

## Tensile Properties and Strain Response of Cu-Al Bi-Metal Tube

(Sifat Regangan dan Tindak Balas Tegangan Tiub Dwi-Logam Cu-Al)

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### ABSTRACT

*Recent high price of copper in global market forced the heat, ventilation, and air condition (HVAC) industry players to find alternative materials with relatively lower market price compared to copper such as aluminium for replacement. This study characterizes tensile properties and strain response of new Cu-Al bi-metal tubes i.e. aluminium clad copper (ACC) and copper clad aluminium (CCA) in order to look at the possibility of applying the bi-metal tubes in HVAC industries. The result shows that tensile properties of CCA tubes was higher than that of ACC bi-metal tubes in two different strain rates of  $1 \times 10^{-3}$  and  $1 \times 10^{-1} \text{ sec}^{-1}$ . Also, Strain response refers to the sample elongation at break shows a higher elongation value of CCA samples compared to ACC.*

*Keywords: Copper; aluminium; bi-metal tube; tensile properties; stress-strain response*

### ABSTRAK

*Pada masa kini, harga tembaga yang tinggi di pasaran global memaksa pemain industri haba, pengudaraan dan penghawa dingin (HVAC) untuk mencari bahan-bahan alternatif yang lebih rendah pada harga pasaran berbanding harga tembaga seperti aluminium sebagai ganti. Kajian ini mencirikan tentang sifat regangan dan tindak balas tegangan tiub dwi-logam Cu-Al seperti aluminium bersalut kumprum (ACC) dan kumprum bersalut aluminium (CCA) untuk melihat kemungkinan penggunaan tiub dwi-logam di dalam HVAC industri. Keputusan menunjukkan sifat regangan tiub CCA lebih tinggi daripada tiub dwi-logam ACC dengan menunjukkan dua kadar tegangan yang berbeza iaitu  $1 \times 10^{-3}$  dan  $1 \times 10^{-1} \text{ sec}^{-1}$ . Selain itu, tindak balas tegangan merujuk kepada pemanjangan sampel sehingga putus mempunyai nilai yang lebih tinggi pada sampel CCA berbanding dengan sampel ACC.*

*Kata kunci: Kuprum; aluminium; tiub dwi-logam; sifat regangan; tindakbalas tegangan-terikan*

### INTRODUCTION

Copper is a very well-known material with excellent properties for conducting heat and electricity. It also demonstrates very good mechanical and corrosion-resistant properties which lead to the widely use of these metals in electrical and electronic industry, heat exchangers, cooling, plumbing etc. (Gueydan et al. 2014; Karamiş et al. 2003).

However, the increasing of copper price of about 20-25% in global market has forced the industry players to find alternative materials for replacing copper. Aluminum is one of the highlighted materials because of its light weight metal with relatively lower market price as compared to copper (Khosravifard & Ebrahimi 2010).

A new product of bi-metal tube consists of copper and aluminum with metallurgical bonding has given an alternative to the industry as the usage of copper in a bi-metal tube is only 30% which is caused low mass and the remaining material is replaced by aluminum which relatively low in cost (Kang et al. 2002; Kim & Hong 2013; Rhee et al. 2004; Zhao et al. 2014). There are only few studies by Liou & Zhao (2001), Paramsothy et al. (2008), Baghdadi et al. (2013), and Sajuri et al. (2014) have been reported on

the tensile properties of bi-metal materials. However, there is no study reported on the strain response of Cu-Al bi-metal tubes during tensile testing.

Therefore, this study aims to investigate the tensile properties and strain response of Cu-Al tubes i.e. copper clad aluminium (CCA) and aluminum clad copper (ACC) tubes in order to evaluate the possibility of implementing the bi-metal tubes in heating, ventilation, and air conditioning (HVAC) industry.

### EXPERIMENTAL PROCEDURES

The material used in this study was Cu-Al bi-metal tubes i.e. ACC and CCA of 12.7 mm in diameter. Tensile test was performed on tube samples with a specimen length of 70 mm under two different strain rates of  $1 \times 10^{-1}$  and  $1 \times 10^{-3} \text{ sec}^{-1}$ . Tensile samples were cut from tubes by using EDM wire cutting machine.

Figure 1 shows machined samples and its dimension. To avoid the sample to become dent at the gripping position during test, an insert plug was inserted into both ends of the tube sample as shown in Figure 2. Tensile test was performed on a Zwick-Roell universal testing machine with a capacity

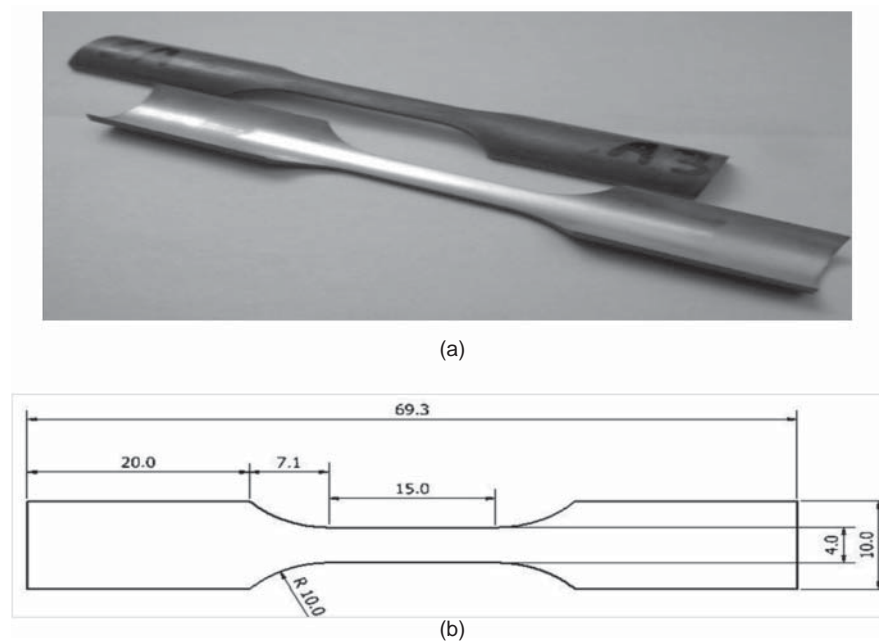


FIGURE 1. Tensile testing sample of bimetal tube (a) Cut tensile testing sample of bimetal tube (b) Bi-metal tube sample size (mm)

of 100 kN. Two KYOWA strain gauges with gage length of 2 mm were mounted on the Al and Cu surfaces to measure strain response of each surface during tensile loading.

strain rate. This is believed due to the higher thickness ratio of Cu/Al in CCA sample compared to that of Cu/Al ratio in ACC (Baghdadi et al. 2013). Further, the higher strain rate resulted in higher tensile properties.

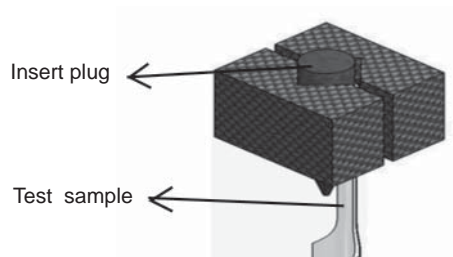


FIGURE 2. Test sample gripping configuration

TABLE 1. Tensile properties of ACC and CCA in different strain rates

| Strain Rate (S <sup>-1</sup> ) | Sample | Elasticity Modulus (GPa) | Yield Stress (MPa) | Ultimate Stress (MPa) | Elongation (%) |
|--------------------------------|--------|--------------------------|--------------------|-----------------------|----------------|
| 10 <sup>-3</sup>               | CCA    | 55                       | 106                | 150                   | 35             |
|                                | ACC    | 50                       | 101                | 131                   | 26             |
| 10 <sup>-1</sup>               | CCA    | 55                       | 113                | 168                   | 36             |
|                                | ACC    | 54                       | 94                 | 138                   | 32             |

## RESULT AND DISCUSSION

### TENSILE TEST

Two different strain rates were applied to the samples test to identify the tensile properties and strain response. Strain rates used in this test were  $1 \times 10^{-3}$  and  $1 \times 10^{-1} \text{ sec}^{-1}$ . Table 1 shows the results of tensile test samples of CCA and ACC with two different strain rates. The CCA at strain rate of  $1 \times 10^{-3} \text{ sec}^{-1}$  showed an elastic modulus of 55 GPa, yield stress of 106 MPa, ultimate stress of 150 MPa and elongation of 35%; tensile of CCA at higher strain rate of  $1 \times 10^{-1} \text{ sec}^{-1}$  resulted similar tensile properties with that of  $1 \times 10^{-3} \text{ sec}^{-1}$ .

However, differences were observed on the tensile properties of ACC and CCA samples. Tensile properties of CCA samples were higher than the ACC samples of the same

### STRAIN RESPONSE

In the tensile test, strain gages bonded to Al and Cu layers of each sample. It aims to see the strain response of both these metals in Cu-Al bimetallic tube. Strain response of both the metal layer can be observed in the graph of strain versus time in Figures 3 & 4.

Strain responses of Al and Cu versus time for CCA sample in the strain rate of  $1 \times 10^{-3} \text{ sec}^{-1}$  are shown in Figure 3(a). The strain response of Cu was higher than Al. However, Cu strain suddenly declined at 80 seconds. This happened because the thin Cu layer was separated from the Al layer and broke. Figure 3(b) presents the strain response of ACC sample at the same strain rate. The Al strain response started to decline at 65 seconds because of breaking of Al layer. Strain response of bi-metal tube in strain rate of  $1 \times 10^{-3} \text{ sec}^{-1}$  more

clearly showed that the strain response of Cu is higher than Al in the same period for each sample to the linear region of the elastic state.

In the tensile test with strain rate of  $1 \times 10^{-1} \text{ sec}^{-1}$ , the reaction of Cu layer was higher than Al layer for sample CCA

as seen in Figure 4(a). However, strain response of Al layer was higher than Cu in ACC as shown in Figure 4(b). The strain of Cu decreased after time passed 1.0 seconds. Initial decrease was due to breaking of Cu layer before the Al layer.

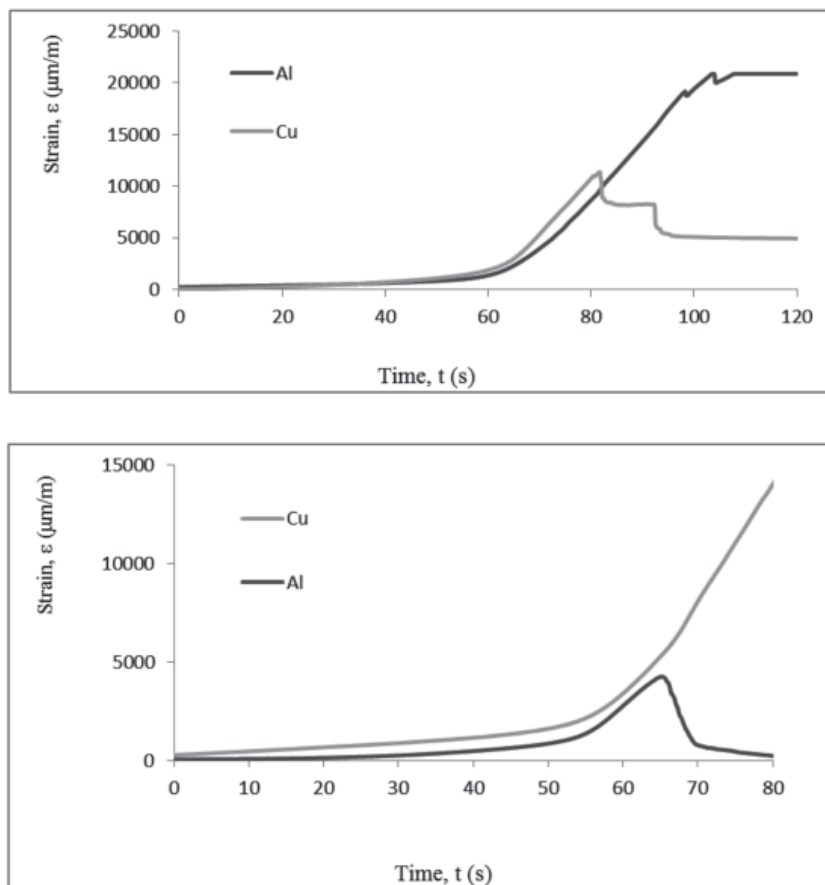


FIGURE 3. Strain responses of (a) CCA and (b) ACC at  $1 \times 10^{-3} \text{ sec}^{-1}$

#### CONCLUSION

Tensile properties and strain response of Cu-Al tubes i.e. copper cladded aluminum (CCA) and aluminum cladded copper (ACC) tubes were investigated in this paper. Based on the tensile test results, it was observed that the tensile properties of the CCA were higher than ACC in both strain rates of  $1 \times 10^{-1}$  and  $1 \times 10^{-3} \text{ sec}^{-1}$ . In addition, the higher strain rate obtained the higher tensile properties. Also, strain response of copper layer was higher than aluminum either CCA or ACC samples for strain rate  $1 \times 10^{-3} \text{ s}^{-1}$ .

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#### REFERENCES

- Baghdadi, A., Sajuri, Z. & Syarif, J. 2013. Study on microstructure and tensile properties of new cu-al bi-metal tubes versus pure copper tubes. *Applied Mechanics and Materials* 420: 160-166.
- Gueydan, A., Domengès, B. & Hug, E. 2014. Study of the Intermetallic growth in copper-clad aluminum wires after thermal aging. *Intermetallics*. 50: (34-42).
- Jiao, H. & Zhao, X.-L. 2001. Material ductility of very high strength (vhs) circular steel tubes in tension. *Thin-walled structures* 39(11): 887-906.
- Kang, C. G., Jung, Y. J. & Kwon, H. C. 2002. Finite element simulation of die design for hot extrusion process of Al/Cu clad composite and its experimental investigation. *Journal of Materials Processing Technology* 124(1-2): 49-56.

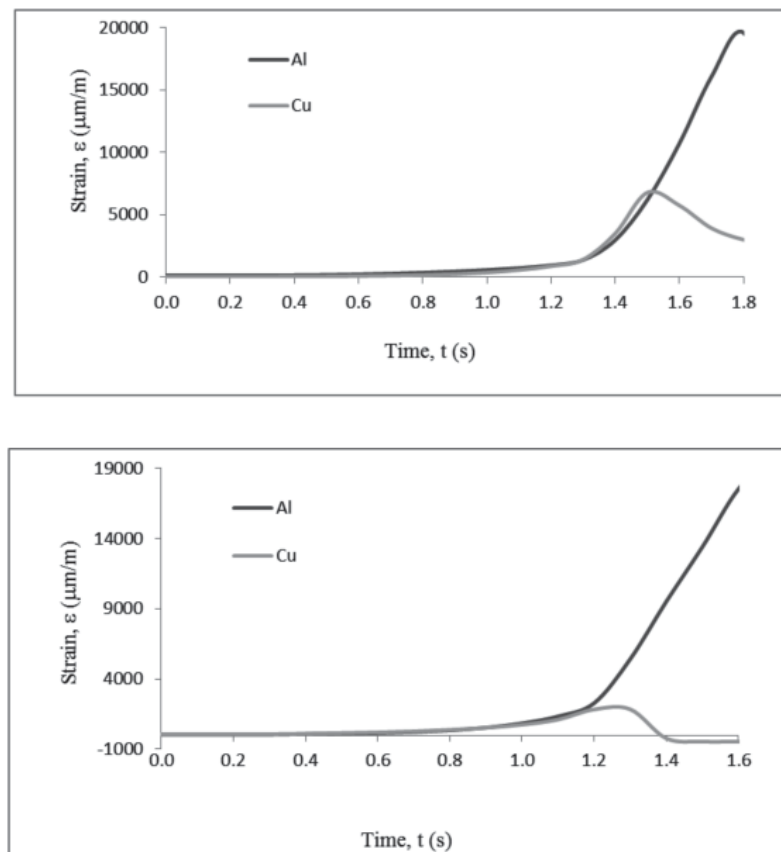


FIGURE 4. Strain responses of (a) CCA and (b) ACC at  $1 \times 10^{-1} \text{ sec}^{-1}$

- Karamış, M. B., Taşdemirci, A. & Nair, F. 2003. Microstructural analysis and discontinuities in the brazed zone of copper tubes. *Journal of Materials Processing Technology* 141(3): 302-312.
- Khosravifard, A. & Ebrahimi, R. 2010. Investigation of parameters affecting interface strength in Al/Cu clad bimetal rod extrusion process. *Materials & Design* 31(1): 493-499.
- Kim, I.-K. & Hong, S. I. 2013. Effect of heat treatment on the bending behavior of tri-layered Cu/Al/Cu composite plates. *Materials & Design* 47(590-598).
- Paramsothy, M., Srikanth, N. & Gupta, M. 2008. Solidification processed Mg/Al bimetal macrocomposite: microstructure and mechanical properties. *Journal of Alloys and Compounds* 461(1): 200-208.
- Rhee, K. Y., Han, W. Y., Park, H. J. & Kim, S. S. 2004. Fabrication of aluminum/copper clad composite using hot hydrostatic extrusion process and its material characteristics. *Materials Science and Engineering: A* 384(1-2): 70-76.
- Sajuri, Z., Baghdadi, A., Mahmud, M. F. & Syarif, J. 2014. Fatigue and mechanical properties of aluminium-copper bi-metal tubes. *Advanced Materials Research* 896(626-629).
- Zhao, J.-L., Jie, J.-C., Chen, F., Chen, H., Li, T.-J. & Cao, Z.-Q. 2014. Effect of immersion ni plating on interface microstructure and mechanical properties of Al/Cu bimetal. *Transactions of Nonferrous Metals Society of China* 24(6): 1659-1665.

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